

TeVatron Direct CP Violation Results

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Abstract

I report some recent results on direct CP violation measurements in hadronic decays collected by the upgraded Collider Detector (CDF II) at the Fermilab Tevatron: CP -violating asymmetries in the two-body non-leptonic charmless decays of b -hadrons, the first reconstruction in hadron collisions of the suppressed decays $B^- \rightarrow D(\rightarrow K^+\pi^-)K^-$ and $B^- \rightarrow D(\rightarrow K^+\pi^-)\pi^-$, and the measurement of TP asymmetries in the $B_s^0 \rightarrow \phi\phi$ decays.

1 Introduction

Non-invariance of the fundamental interactions under the combined symmetry transformation of charge conjugation and parity inversion (CP violation) is an established experimental fact. The vast majority of experimental data are well described by the standard model (SM), and have supported the success of the Cabibbo-Kobayashi-Maskawa (CKM) theory of quark-flavor dynamics. However, additional sources of CP violation are required to explain the matter–antimatter asymmetry of the Universe in standard big-bang cosmology. The heavy flavour sectors have not yet been fully covered by experiments so far, thus the presence of a new source of CP violation can not be excluded. An unexpected hint of CP violation would have profound consequences on our understanding of fundamental interactions.

The CDF II experiment at the Tevatron $p\bar{p}$ collider established that extensive and detailed exploration of the b -quark dynamics is possible in hadron collisions, with results competitive and supplementary to those from e^+e^- colliders. This has provided a rich and highly rewarding physics program and, still more important, a tremendous legacy for currently operating and future experiments, such as LHCb.

2 Two-body non-leptonic charmless B decays

In recent times, the pattern of direct CP violation in charmless mesonic decays of B mesons has shown some unanticipated discrepancies from expectations. Under standard assumptions of isospin symmetry and smallness of contributions from higher-order processes, similar CP asymmetries are predicted for $B^0 \rightarrow K^+\pi^-$ and $B^+ \rightarrow K^+\pi^0$ decays [1, 2]. However, experimental data show a significant discrepancy [3], which has prompted intense experimental and theoretical activity. Several simple extensions of the SM could accommodate the discrepancy [4], but uncertainty on the contribution of higher-order SM amplitudes has prevented a firm conclusion [5, 6]. Measurements of direct CP violation in $B_s^0 \rightarrow K^-\pi^+$ decays have been proposed as a nearly model-independent test for the presence of non-SM physics [7, 8]. The relationships between charged-current quark couplings in the SM predict a well-defined hierarchy between direct CP violation in $B^0 \rightarrow K^+\pi^-$ and $B_s^0 \rightarrow K^-\pi^+$ decays, yielding a significant asymmetry for the latter, of about 30%. This large effect allows easier experimental investigation and any discrepancy may indicate contributions from non-SM amplitudes. Supplementary information could come from CP violation in bottom baryons. Interest in charmless b -baryon decays is prompted by branching fractions recently observed being larger than expected [9, 10, 11]. Asymmetries up to about 10% are predicted for $\Lambda_b^0 \rightarrow pK^-$ and $\Lambda_b^0 \rightarrow p\pi^-$ decays in the SM [10, 12], and are accessible with current available samples. High precision measurements of the violation of CP symmetry in charmless modes remains, therefore, a very interesting subject of study and may provide useful information to our comprehension of this discrepancy.

We report the measurements of direct CP violation in decays of bottom mesons and bottom baryons, performed in 9.3 fb^{-1} of $\bar{p}p$ collisions at $\sqrt{s} = 1.96 \text{ TeV}$, collected by CDF II at the Fermilab Tevatron. An extended unbinned likelihood fit [13, 14], incorporating kinematic (invariant mass and momenta) and particle identification (dE/dx) information, is used to determine the fraction of each individual mode in the sample. The fit projection on the invariant $\pi\pi$ -mass is reported in fig. 1. We measure $A_{CP}(B^0 \rightarrow K^+\pi^-) = -0.083 \pm 0.013(\text{stat}) \pm 0.003(\text{syst})$ [13] with a significance more than 5σ . The uncertainty of the observed asymmetry is consistent and of comparable accuracy with current results from asymmetric e^+e^- colliders [3] and LHCb [15]. We also measure $A_{CP}(B_s^0 \rightarrow K^-\pi^+) = +0.22 \pm 0.07(\text{stat}) \pm 0.02(\text{syst})$ [13] with a significance of 2.9σ . This result confirms the LHCb evidence [15] with the same level of resolution. The averaged value between this result and LHCb measurement is equal to $A_{CP}(B_s^0 \rightarrow K^-\pi^+)_{\text{mean}} = +0.24 \pm 0.05$ which has a significance of 4.8σ . This represents a strong evidence of CP violation in the B_s^0 meson system. The observed asymmetries $A_{CP}(\Lambda_b^0 \rightarrow pK^-) = -0.09 \pm 0.08(\text{stat}) \pm 0.04(\text{syst})$ [13] and $A_{CP}(\Lambda_b^0 \rightarrow p\pi^-) = +0.07 \pm 0.07(\text{stat}) \pm 0.03(\text{syst})$ [13] are consistent with zero. The current experimental precision allows for the first time to exclude large CP violation effects

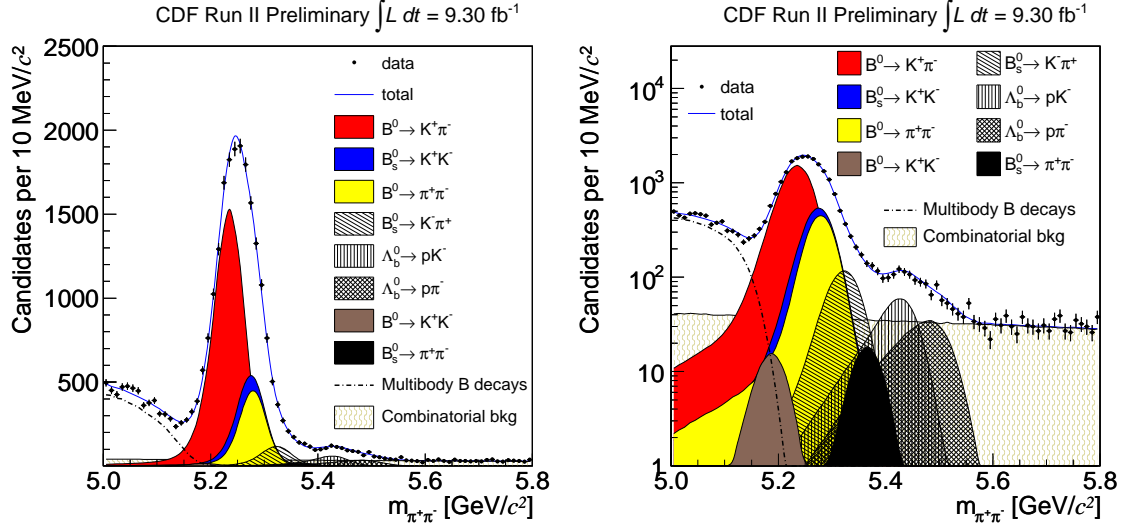


Figure 1: Mass distribution of reconstructed candidates, $m_{\pi\pi}$. The charged pion mass is assigned to both tracks. The total projection and projections of each signal and background component of the likelihood fit are overlaid on the data distribution. Signals and multi-body B background components are shown stacked on the combinatorial background component. Linear scale (left panel) and logarithmic scale (right panel).

in these decays, however it is not yet sufficient for a conclusive discrimination between the standard model prediction (8%) and much suppressed values ($\approx 0.3\%$) expected in R-parity violating supersymmetric scenarios [12]. The observed asymmetries are consistent with the previous results from CDF [16] and supersede them.

3 Angle γ from $B^- \rightarrow DK^-$

Conventionally, CP violating observables are written in terms of the angles α , β and γ of the Unitarity Triangle, obtained from one of the unitarity conditions of the CKM matrix. While the resolution on α and β reached a good level of precision, the measurement of γ is still limited by the smallness of the branching ratios involved in the processes. Among the various methods for the γ measurement, those which make use of the tree-level $B^- \rightarrow D^0 K^-$ decays have the smallest theoretical uncertainties. In fact γ appears as the relative weak phase between two amplitudes, the favored $b \rightarrow c\bar{u}s$ transition of the $B^- \rightarrow D^0 K^-$, whose amplitude is proportional to $V_{cb}V_{us}$, and the color-suppressed $b \rightarrow u\bar{c}s$ transition of the $B^- \rightarrow \bar{D}^0 K^-$, whose amplitude is proportional to $V_{ub}V_{cs}$. The interference between D^0 and \bar{D}^0 , decaying into the same

final state, leads to measurable CP -violating effects, from which γ can be extracted. The effects can be enhanced by choosing interfering amplitudes that are of the same order of magnitude. All methods require no tagging or time-dependent measurements, and many of them only involve charged particles in the final state.

In a data sample of about 7 fb^{-1} we report the first reconstruction in hadron collisions of the suppressed decays $B^- \rightarrow D(\rightarrow K^+\pi^-)K^-$ and $B^- \rightarrow D(\rightarrow K^+\pi^-)\pi^-$, which are the main ingredient of the ADS method [17]. Also in this case an extended unbinned likelihood fit, incorporating kinematic (invariant mass) and particle identification (dE/dx) information, is used to determine the fraction of each individual modes. CDF measures the following asymmetries: $A_{ADS}(K) = -0.82 \pm 0.44(\text{stat}) \pm 0.09(\text{syst})$ and $A_{ADS}(\pi) = 0.13 \pm 0.25(\text{stat}) \pm 0.02(\text{syst})$ [18], and for the ratios of doubly Cabibbo suppressed mode to flavor eigenstate CDF finds $R_{ADS}(K) = [22.0 \pm 8.6(\text{stat}) \pm 2.6(\text{syst})] \times 10^{-3}$ and $R_{ADS}(\pi) = [2.8 \pm 0.7(\text{stat}) \pm 0.4(\text{syst})] \times 10^{-3}$ [18]. The results are in agreement with existing measurements performed at $\Upsilon(4S)$ resonance [19] and very recently at LHCb [20].

4 $B_s^0 \rightarrow \phi\phi$

Triple product (TP) asymmetries are odd under time-reversal, and can be generated either by final state interactions or CP violation. In flavor untagged samples, where the initial B flavor is not identified, TP asymmetries can be shown to signify genuine CP violation [21]. In this respect they are very sensitive to the presence of new physics in the decay since they do not require a strong-phase difference between new and SM amplitudes, as opposed to direct CP asymmetries [22]. The TP asymmetry is defined as $\mathcal{A}_{\text{TP}} = \frac{\Gamma(\text{TP}>0) - \Gamma(\text{TP}<0)}{\Gamma(\text{TP}>0) + \Gamma(\text{TP}<0)}$, where Γ is the decay width for the given process. In $B_s^0 \rightarrow \phi\phi$ decays two TP asymmetries can be studied, corresponding to the two interference terms between amplitudes with different CP . These asymmetries are predicted to vanish in the SM, and an observation of a non-zero asymmetry would be an unambiguous sign of NP [22].

We report the first measurement of TP asymmetries in the $B_s^0 \rightarrow \phi\phi$ decays reconstructed at CDF, using a data sample of 2.9 fb^{-1} of integrated luminosity and we measure $A_u = -0.007 \pm 0.064 \pm 0.018$ and $A_v = -0.120 \pm 0.064 \pm 0.016$ [23] in agreement with recent world's best measurement from LHCb [24].

5 Conclusion

CDF experiment at the Tevatron keeps providing excellent results in the exploration of Heavy Flavor Physics, owing to CP -symmetric initial states in $\sqrt{s} = 1.96 \text{ TeV}$ $p\bar{p}$ collisions, large event samples collected by well-understood detector, and mature

analysis techniques. In summary, this short write-up reports on the measurements of CP -violating asymmetries in the two-body non-leptonic charmless decays of b -hadrons, on the first reconstruction in hadron collisions of the suppressed decays $B^- \rightarrow D(\rightarrow K^+\pi^-)K^-$ and $B^- \rightarrow D(\rightarrow K^+\pi^-)\pi^-$, and on the measurement of TP asymmetries in the $B_s^0 \rightarrow \phi\phi$ decays.

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